EXPERIMENTAL STUDY AND NUMERICAL MODELLING OF WOVEN FABRIC KENAF FIBER COMPOSITES HYBRID ADHESIVELY BONDED-BOLTED JOINTS

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For my beloved mother and father

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ABSTRACT

Couple with natural fiber composite parts, hybrid joints provide better joint strength than using separate joints. There are limited studies on structures response and strength prediction work on hybrid joints that limits its applicability. The aim of present study is to conduct experimental datasets on woven fabric kenaf fiber reinforced polymer (KFRP) and carbon fiber reinforced polymer (CFRP) composite hybrid joints under quasi-static testing and to carry out the strength prediction works subsequently by implementing physically-based traction-separation constitutive law. Testing series investigated includes variation of joint types, normalized *W/d* = 2 to 5, reinforcing fiber composites, lay-up types, plate thickness and bolt loads. Experimental observations and bearing stress at failures were conducted, the datasets were then used as validation works in FEA modelling. All KFRP hybrid joint series demonstrated net-tension failure mode associated to stress concentration at the vicinity of notch tip. Initially, strength prediction works were attempted by implementing various numerical approaches and fully XFEM techniques was adopted to all series as it provides promising results with better physically representation and less computational time. Good agreements between experimental datasets and predicted bearing stress at failure were found in KFRP hybrid joints with average discrepancy of less than 23%. It was found that combinations of thicker and cross-ply lay-up gives the best prediction of less than 2 % (where experimental datasets and FEA output were given as 201 N/mm^2 and 198 N/mm^2 respectively) due to better repetitive lay-up with implementation of smeared-out properties. Less significant effects from bolt loads and reinforcing fibers were found for both joint types. It can be concluded that fully XFEM technique able to provide as a unified prediction tools in hybrid joints of most composite materials with reasonable agreements.

ABSTRAK

Gabungan komposit gentian semula jadi dengan sambungan hibrid memberikan kekuatan yang lebih baik daripada menggunakan sambungan secara berasingan. Kajian respon struktur dan kerja ramalan kekuatan sedia ada untuk sambungan jenis ini adalah terhad yang membataskan kebolehgunaannya. Objektif kajian projek ini adalah untuk mendapatkan set data eksperimen sambungan hibrid komposit fabrik tenunan gentian kenaf bertetulang polimer (KFRP) dan gentian karbon bertetulang polimer (CFRP) di bawah ujian tegangan kuasi-statik dan kerja ramalan kekuatan dilaksanakan dengan menggunakan model bahan berasaskan fizikal iaitu hubungan daya tarikan -pemisahan. Siri ujikaji terlibat termasuk jenis sambungan, siri nisbah *W/d* =2 hingga 5, jenis komposit gentian, jenis urutan lapisan, ketebalan plat dan bebanan bolt. Pemerhatian daripada eksperimen dan kekuatan galas telah ditentukan, data tersebut kemudiannya dibandingkan dengan output FEA. Semua sambungan hibrid KFRP menunjukkan mod kegagalan *net-tension* berkait rapat dengan tumpuan tegasan di sekitar tip bukaan. Percubaan awal dalam kerja ramalan dijalankan dengan pelbagai teknik berbeza dan teknik XFEM penuh diterimapakai kerana keputusan yang lebih memuaskan disamping cenderung secara fizikal dan mengoptimumkan masa pengiraan. Perbandingan kekuatan galas sambungan hybrid KFRP di antara set data eksperimen dan kerja ramalan didapati baik dengan menunjukkan purata percanggahan kurang daripada 23%. Gabungan plat yang lebih tebal dan *cross-ply* menunjukkan kerja ramalan yang lebih baik iaitu kurang daripada 2% (di mana data eksperimen dan output FEA adalah 201 N/mm^2 dan 198 N/mm^2) disebabkan ulangan lapisan yang ketara disebabkan pelaksanaan *smeared out*. Perbezaan yang kurang ketara didapati daripada kesan bebanan bolt dan jenis gentian komposit pada kedua-dua jenis gabungan. Secara rumusan, teknik XFEM penuh dapat dijadikan sebagai alat ramalan untuk sambungan hibrid dalam kebanyakan bahan komposit dengan menunjukkan perbandingan yang baik.

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LIST OF SYMBOLS AND ABBREVIATIONS

ASTM	-	American Society for Testing Materials
BK	-	Benzeggagh-Kenane failure criterion
CQ/CS	-	Carbon fiber quasi-isotropic
CX	-	Carbon fiber cross-ply
CDG	-	Critical damage growth
CGM	-	Crack growth model
CZM	-	Cohesive zone model
CFRP	-	Carbon fiber reinforced polymer
DLJ	-	Double-lap joint
DZM	-	Damage Zone Model
FEA	-	Finite element analysis
FEM	-	Finite element method
FRP	-	Fiber reinforced polymer
FT	-	Finger-tight case
GFRP	-	Glass fiber reinforced polymer
KFRP	-	Kenaf fiber reinforced polymer
LEFM	-	Linear elastic fracture mechanics
PDM	-	Progressive damage modelling
PE	-	Polyethylene
PP	-	Polypropylene
PS	-	Polystyrene
PV	-	Polyvinyl chloride
PQ/PS	-	Plain weave quasi-isotropic
PX	-	Plain weave cross-ply
SEN	-	Single-edge notch
SLJ	-	Single-lap joint

VCCT	-	Virtual crack closure technique
XFEM	-	Extended finite element method
2-D	-	Two-dimensional
3-D	-	Three-dimensional
a	-	Longitudinal distance from hole edge/crack length
a_i	-	Enriched nodal degree of freedom vector
B	-	Plate width
$b_i^{\propto}$	-	Nodal enriched degree of freedom vector of nodes
t	-	Plate thickness
C	-	Compliance
d	-	Hole diameter
D	-	Scalar damage variable
e	-	End-distance
E_1	-	Longitudinal Young's modulus
E_2	-	Transverse Young's modulus
E_x	-	Laminate longitudinal Young's modulus
E_y	-	Laminate transverse Young's modulus
$\varepsilon_{n,max}$	-	Maximum nominal strain normal-only mode
$\varepsilon_{s,max}$	-	Maximum nominal strain shear-only mode first-direction
$\varepsilon_{t,max}$	-	Maximum nominal strain shear-only mode second direction
F	-	Reaction force
$F_{\alpha}(x)$	-	Related elastic asymptotic crack-tip functions
G_{xy}	-	Laminate shear modulus
G_{12}		In-plane shear modulus (fiber direction)
G_1/G_c	-	Fracture energy
G_c^*	-	Apparently fracture energy
G_n	-	Fracture energy normal-only mode
G_s/ G_{IC}	-	Fracture energy mode first direction
G_t/ G_{IIC}	-	Fracture energy mode second direction
$H(x)$	-	Discontinuous jump shape function (in enriched element)
K	-	Elastic stiffness matrix
K_T^{∞}/K_T	-	stress concentration factor
K_r	-	Crack interior

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